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EXTENDED AERATION PACKAGE PLANT PERFORMANCE EVALUATION

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ABSTRACT

The performance of 20 extended aeration activated sludge package plants of design capacities from 8 to 454 m^3/d was investigated. The main parameters used in the evaluation were: mixed liquor temperature, dissolved oxygen, pH, suspended solids, and sludge volume index; influent and effluent suspended solids and BOD_5; and flow rates and flow patterns. The performance data for these plants, operated under actual conditions, were compared with similar data for plants operated under optimum controlled conditions.

Nitrification/denitrification, inadequate biomass concentration, clogging of sludge return systems, hydraulic overload, inadequate aeration, low mixed liquor pH, poor maintenance and lack of operator training were the most common problems identified.

RÉSUMÉ

Vingt petites unités à aération prolongée et à boues activités, d'une capacité théorique de 8 à 454 m^3/j ont été évaluées à l'aide des paramètres suivants: température de la liqueur mixte, oxygène dissous, pH, matières en suspension (MES) et indice de volume des boues; MES et DBO_5 avant et après traitement; débits et formes d'écoulement. Les résultats obtenus dans des conditions réelles ont été comparés à des résultats obtenus dans des conditions optimisées.

Parmi les causes de difficultés les plus communes on a trouvé la nitrification et la dénitrification, le colmatage du circuit de retour des boues, la surcharge hydraulique, l'aération insuffisante, le pH bas de la liqueur mixte, l'entretien déficient et le manque de formation des opérateurs.

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CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following conclusions and recommendations are based on analyses of samples and measurements of flow from the 20 extended aeration activated sludge package plants evaluated in this study, and on interviews with their owners, suppliers, manufacturers and operators.

1) Of the 20 plants studied, 11 plants achieved effluents with an average BOD_5 of less than 30 mg/L; four plants (two in subdivisions and two in school systems) achieved an average SS of less than 30 mg/L, meeting the 30-30 effluent quality guideline set by the Province of Nova Scotia.
2) The performance of the 20 Nova Scotia plants was compared to that of plants in an NSF study (National Sanitation Foundation, Ann Arbor, Michigan, USA). The NSF plants were manufactured by the same supplier, and treated municipal wastewater with similar flow patterns. Although four Nova Scotia plants produced effluents of equal or better quality, no Nova Scotia plant discharged an effluent having both BOD_5 and SS equal to or less than that produced in the corresponding American systems.
3) Of the 20 plants studied, seven produced an average effluent BOD_5 and/or SS greater than 80 mg/L. One plant had an average effluent BOD_5 of 300 mg/L.
4) The unacceptable performance of these systems resulted from problems in the operation of the plants, process problems and problems with the activated sludge package plant equipment. Operational problems were mainly due to insufficient training of operators and improper maintenance of the facilities. Process problems were mainly associated with low mixed liquor suspended solids, low mixed liquor pH, and fluctuations in hydraulic loading. The majority of the process problems could be eliminated if a reliable sludge return system, flow equalization facilities, and sludge treatment and ultimate disposal facilities were provided. The most frequent equipment problems (in order of decreasing frequency of occurrence) were:
    a) clogging of the sludge return system,
    b) comminutor breakdown,
    c) clogging of diffusers,

Extended Aeration Package Plant Performance Evaluation

d) formation of ice in the clarifier in winter,

e) clogging and freezing of the chlorine feed line, and

f) compressor breakdown.

Recommendations

General

1) It is essential that operators understand the basic principles of the biological process if they are to be able to properly operate the pollution control system; hence, an operator certification program is recommended to ensure that they receive the necessary training.

2) Operators must be given sufficient time to adequately monitor system performance and for maintenance work. The time required for these activities should be clearly defined.

3) Plants should be visited regularly by inspectors.

To Manufacturers

1) Improved design of sludge return systems, clarifier skimming devices, comminutors and air diffuser systems would reduce maintenance and enhance performance. To provide adequate control of sludge return systems, air-lift equipment should be replaced by positive displacement pumps.

2) Clarifiers must be equipped with sludge scraping mechanisms if adequate control of the sludge inventory in the system is to be maintained.

3) Package plants should be equipped with facilities for proper sampling of comminuted influent. They should also be provided with a V-notch weir for the measurement of flow and, if this is not possible, space to accommodate such a device.

For Further Studies

1) Further studies should be conducted at the seven 'problem' plants (1, 5, 6, 9, 11, 17 and 18) to solve the mechanical and operational problems. These should result in the definition and implementation of an effective operating strategy, which would include monitoring requirements and sludge disposal procedures.

2) It was assumed that biological nitrification was occurring in plants 3, 4, 12 and 19. Additional tests involving measurement of ammonia, nitrite, nitrate, alkalinity and solids retention times should, however, be carried out to determine whether nitrification is indeed occurring. The alkalinity requirements should be calculated

and, if found deficient, the alkalinity should be increased to determine whether this would solve the problems related to low mixed liquor pH.

3) Equalization facilities should be provided for the treatment plants which are presently operating under extreme variations in flow. Following corrective measures, the performance of these systems should be monitored. Because plants 13 and 14 are run in parallel, one could be equalized and the second operated with the present flow variations for comparison. Flow equalization should also be installed and evaluated at plants, 1, 5, 6 and 18, as these plants were hydraulically overloaded during the study period.

1 INTRODUCTION

1.1 Background

Extended aeration activated sludge package plants (henceforth referred to as package plants) have been playing a significant role in Canada in controlling pollution from small isolated communities, trailer parks, subdivisions and, as well, both commercial and non-commercial institutions such as schools, industries, restaurants and motels. Package plants are the obvious and viable choice for providing pollution control for small systems (serving population equivalents less than about 10 000) when the available land space is limited and too expensive to accommodate aerated lagoons, waste stabilization ponds and oxidation ditches.

With the exception of the Halifax-Dartmouth metro areas and the City of Sydney, the population of Nova Scotia is spread through isolated communities, subdivisions, towns and rural areas. Neither Sydney nor the twin cities of Halifax-Dartmouth had central treatment plants at the time of this study (1976). Instead, oxidation ditches, aerated lagoons, waste stabilization ponds, septic tanks, trickling filters, contact stabilization plants and, most of all, package plants (of which there are 250 in Nova Scotia, more than in any other province of Canada) have been used to control water pollution in the province. A detailed study of these package plants has long been overdue in Canada; consequently, Canada Mortgage and Housing Corporation commissioned the Nova Scotia Technical College to study the performance of 20 selected plants.

The National Sanitation Foundation (NSF) at Ann Arbor, Michigan, USA, conducted research in 1965 and 1966 to establish various means of evaluating the performance of package plants. They developed methods of evaluating the performance of these plants (1), as well as methods for evaluating contact stabilization processes (2). The NSF then employed these techniques to evaluate the performance of package plants. In their tests, flow patterns typical of subdivisions and schools were simulated. Suspended solids (SS), five-day biochemical oxygen demand (BOD_5), and chemical oxygen demand (COD) for daily composite samples of influent and effluent were presented as probability plots.

Treatment plants evaluated by NSF were operated in accordance with the manufacturers' instructions with the exception of variations in flow, flow patterns and organic loadings. The source of the wastewater to the NSF plants was influent to the municipal sewage treatment plant at Ann Arbor, Michigan. The equipment employed by

the NSF investigators enabled them to set any flow pattern desired, such as steady state, subdivision and school flow patterns (Figure 1-1). As the NSF study of package plant performance was conducted under near-ideal conditions, the NSF data and certification of performance may be interpreted as demonstrating the potential performance of the package plants.

1.2 Present Study

The Nova Scotia investigation was designed to evaluate the performances of the extended aeration package plants under existing operating conditions. For each of the 20 study sites, detailed information was collected on the design, operation, maintenance, staff requirements, operational problems and cost of operation. The performance data for each of the 20 plants studied were compared to data obtained for similiar plants in the NSF studies.

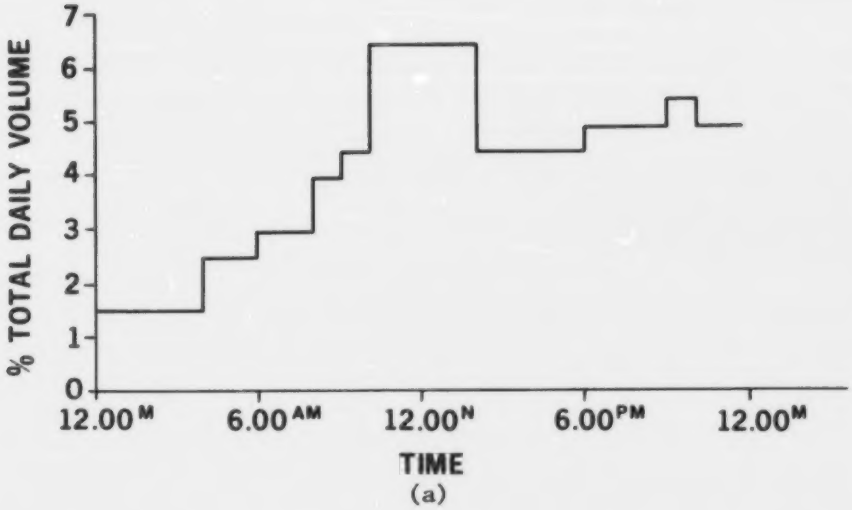
1.3 Scope of the Study

The 20 plants were designed to handle from 8 to 454 m^3/d of domestic wastewater (Table 1-1). The plants represented examples of both normal diurnal flow variations and intermittent flow patterns.

The levels of performance of the 20 plants were determined by measuring the BOD_5 and SS of refrigerated 24-hour composite influent and effluent samples collected for a period of 21 consecutive days. Grab samples of mixed liquor were also analysed every day for SS, dissolved oxygen (DO), sludge volume index (SVI) and temperature. Occasionally, the pH of influent, effluent and mixed liquor samples was recorded.

Effluent flow rates were measured and recorded for all plants. Rainfall data were obtained from the Atlantic Regional Office of the Atmospheric Environment Service, Environment Canada, for the recording stations nearest to the plants.

The following supporting data were collected (whenever available) for each treatment system: process description including sizing of units; the type of waste being treated; organic and hydraulic loading conditions (actual and design); the type of, frequency of, and solutions to operational problems; routine maintenance and inspection performed; the number of staff employed and the amount of time devoted to sampling, analysis, inspection, repair, maintenance, supervision and operation; the level of training of the operators; and the operating costs for chemicals, utilities, power, salaries, repairs, maintenance and miscellaneous items.



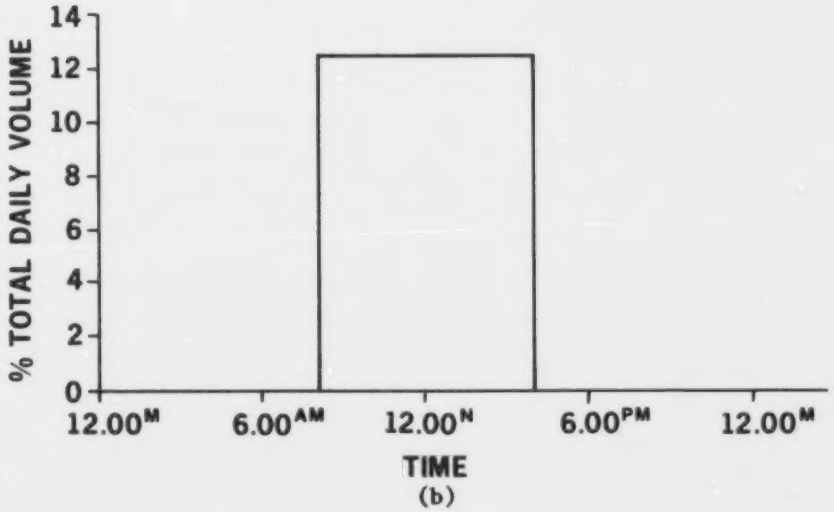


FIGURE 1-1 FLOW PATTERNS SIMULATED DURING THE NSF STUDY
a) Subdivision flow pattern
b) School flow pattern

TABLE 1-1 SUMMARY OF THE SELECTED PACKAGE PLANTS

Plant	Application	Design Capacity (m^3/d)
1	Subdivision	94
2	Subdivision	117
3	Junior High School	29
4	Junior High School	30
5	Subdivision	57
6	Subdivision	57
7	Subdivision	49
8	Training School	14
9	Trailer Park	76
10	Trailer Park	454
11	Trailer Park	15
12	Trailer Park	85
13	Research Institute	57
14	Research Institute	47
15	Housing Quarters	19
16	Office Building	8
17	Subdivision	341
18	High School	57
19	Elementary School	38
20	Restaurant	24

1.4 Criteria for Plant Selection

A preliminary list of 30 package plant systems was investigated. From these, 20 extended aeration activated sludge package plants were selected on the basis of plant accessibility, power supply, safety, and space available for sampling and flow measurements. Four manufacturers, whose plants were certified by the NSF, had supplied (as of 1976) approximately 200 extended aeration package plants in Nova Scotia. Eighteen of these, in approximate proportion to the number of plants supplied by each manufacturer in the province, were selected for the program. The two remaining plants, not certified by the NSF, were provided by two other manufacturers.

Plants serving schools, subdivisions, trailer parks, a research institute, a restaurant, an office building and a housing quarter were included to have as wide a variation in system application as possible. Four school plants were tested. Two of these were monitored during normal academic days and the remaining two were monitored just after summer vacation. This provided an opportunity to study possible problems related to start-up of the biological system.

Plants located in the vicinity of Nova Scotia Technical College were considered most suitable for selection as they were readily accessible. The majority of the plants were within 24 km of the college, with two plants within 100 km. At the beginning of the project it was agreed that the names of the manufacturers and the locations of the plants would not be disclosed.

2 MATERIALS AND METHODS

2.1 General

The study period, which lasted about four and one-half months beginning in the last week of May and ending in the first week of October, 1976, was characterized by mild to warm days and cool nights in most areas where the systems were located. The monthly mean air temperatures were 9.7°C, 16.1°C, 17.3°C, 18.3°C and 14.8°C, for the five months from May to September, respectively.

Plants 1 to 12 were monitored in groups of four at a time. Units 13 to 17 were tested together, and units 18, 19 and 20 were investigated together at the end of the monitoring period.

2.2 Sample Collection

Two automatic composite samplers (manufactured by Sigmamotor Inc., New York, Model WA-2) were installed in each plant, one for sampling influent and the other for sampling effluent. Each sampler, equipped with a constant speed, positive displacement pump, was designed to deliver wastewater to a 5-L refrigerated container kept at 4 ± 1°C. The size of the sample could be controlled by a timer which regulated the "on" and "off" cycles of the sampling pump. The nine automatic samplers employed in the project utilized flexible sampling tubes with 3 mm inside diameter and 1.6 mm wall thickness. The units operated with 115-volt, A.C. power.

2.2.1 Influent Sampling. In most of the package plants raw wastewater, after passing through a comminutor and/or bypass screen, discharged directly into the mixed liquor in the aeration tank. Because the comminutor exit pipe barely cleared the maximum liquid level in the aeration tank, and since there was no holding device, it was impossible to locate the end of the sampling tube so that the comminuted wastewater could be sampled without mixed liquor entering the tube. As a result of this problem, sampling tubes had to be located in a small chamber upstream of the comminutor (with the exception of plant 10). Screening devices were attached to the tube ends to prevent clogging problems; however, toilet paper and other substances quickly covered the screens and acted as filters, keeping significant portions of coarse solids from entering the sampling tubes. The solids deposited on the screen were removed manually once or twice a day, depending on the number of visits to the plant.

In plant 10, the comminutor was located apart from the aeration tank. The comminuted wastewater was transported to the aeration tank through an open channel in which the sampler tube was located, making it possible to pump comminuted wastewater to the sampler. Unlike the other 19 plants, which had their sampling tubes located upstream of the comminutor, the influent samples collected at plant 10 were more representative of comminuted influent.

2.2.2 Effluent Sampling. The absence of coarse solids in the effluent enabled collection of representative samples without the problems associated with sampling the influent. Depending on plant configurations, the inlet end of the sampling tube was located either in the clarifier near the overflow weir or inside the weir trough. In this way, settled but unchlorinated samples were collected for analysis.

2.2.3 Mixed Liquor Grab Sampling. Once a day mixed liquor was collected manually from each plant. The grab samples were obtained by collecting a surface sample from the aeration tank at the location farthest from the diffusers.

Aeration tanks in six plants were subject to intermittent aeration. On certain days the aeration tank was subjected to a quiescent cycle at the time of the field visit. Field crews were instructed to wait until the end of this cycle, and then to allow a further 10 minutes of the following aeration cycle before making the field measurements. Mixed liquor samples were collected for laboratory analyses following these measurements.

2.3 Sample Analyses

Laboratory analyses of samples was generally initiated on the day of collection. The interval between collection and analyses never exceeded 24 hours for plants 1 to 19. However, in the case of plant 20, located about 100 km from the college, the samples were transported by commercial buses and, occasionally, the delivery was delayed resulting in a 48-hour interval between collection and analyses.

Influent and effluent samples were analysed daily for BOD_5 and SS, and occasionally for pH. Mixed liquor samples were analysed for temperature, DO, SVI and SS each day, and occasionally for pH.

Temperature and DO of mixed liquor samples were measured in the field using an oxygen meter (Yellow Spring Instrument Company, Yellow Springs, Ohio, USA). The 30-minute settling test for mixed liquor solids was also performed in the field. The SS and pH tests were conducted in the laboratory. Duplicate mixed liquor samples (volumes ranging from 5 to 50 mL) were filtered and the average of two tests then recorded.

Because low-capacity vacuum pumps developed motor heating problems after prolonged use, low sample volumes had to be filtered during the initial few weeks. Larger sample volumes could be filtered for the remainder of the study after the smaller pumps were replaced by larger units. The pH meter was calibrated daily using at least two standard buffer solutions.

The procedures recommended in Standard Methods (3) were employed to determine BOD_5 and SS, with the following exceptions. The oxygen meter, calibrated once a week using the azide modification of the Winkler method, was used to measure initial and final DO in BOD bottles. A dosage of 0.5 mg of allylthiorea (ATU) was added to every litre of dilution water to prevent nitrification during the five-day BOD test. At this ATU dosage level, Montgomery and Borne report that carbonaceous oxidation is not significantly influenced (4). The inhibitor, ATU, was used to prevent the action of nitrifying bacteria which would otherwise interfere with the measurement of the true BOD_5 (i.e., the biochemical oxygen demand exerted purely as a result of carbonaceous material).

During the initial four weeks, duplicate samples of influent and effluent were filtered for the SS test and the average of the two values then recorded. As the laboratory personnel gained experience, only one sample of the influent and one sample of the effluent were filtered. Because, however, the mixed liquor was often characterized by a heterogenous mass of solids, duplicate mixed liquor samples were filtered throughout the study.

2.4 Flow Measurement

V-notch weirs were chosen for the measurement of flow rates. They have an inherently greater accuracy than other weir configurations at the comparatively low flows that were anticipated in the selected treatment plants.

Two different systems were employed to measure and record the head of waste liquid flowing through the V-notch weirs. An electronic transmitter and strip-chart recorder (Figure 2-1) were used wherever possible, but, in situations where plant configuration limited the use of the electronic equipment, an improvised pneumatic head-measuring device driving a clockwork recorder was used (Figure 2-2).

2.4.1 Equipment.

2.4.1.1 Electronic system. This system (Figure 2-1) consists of a weir box, a capacitance transmitter, a stilling well and a recorder. It works on the principle that

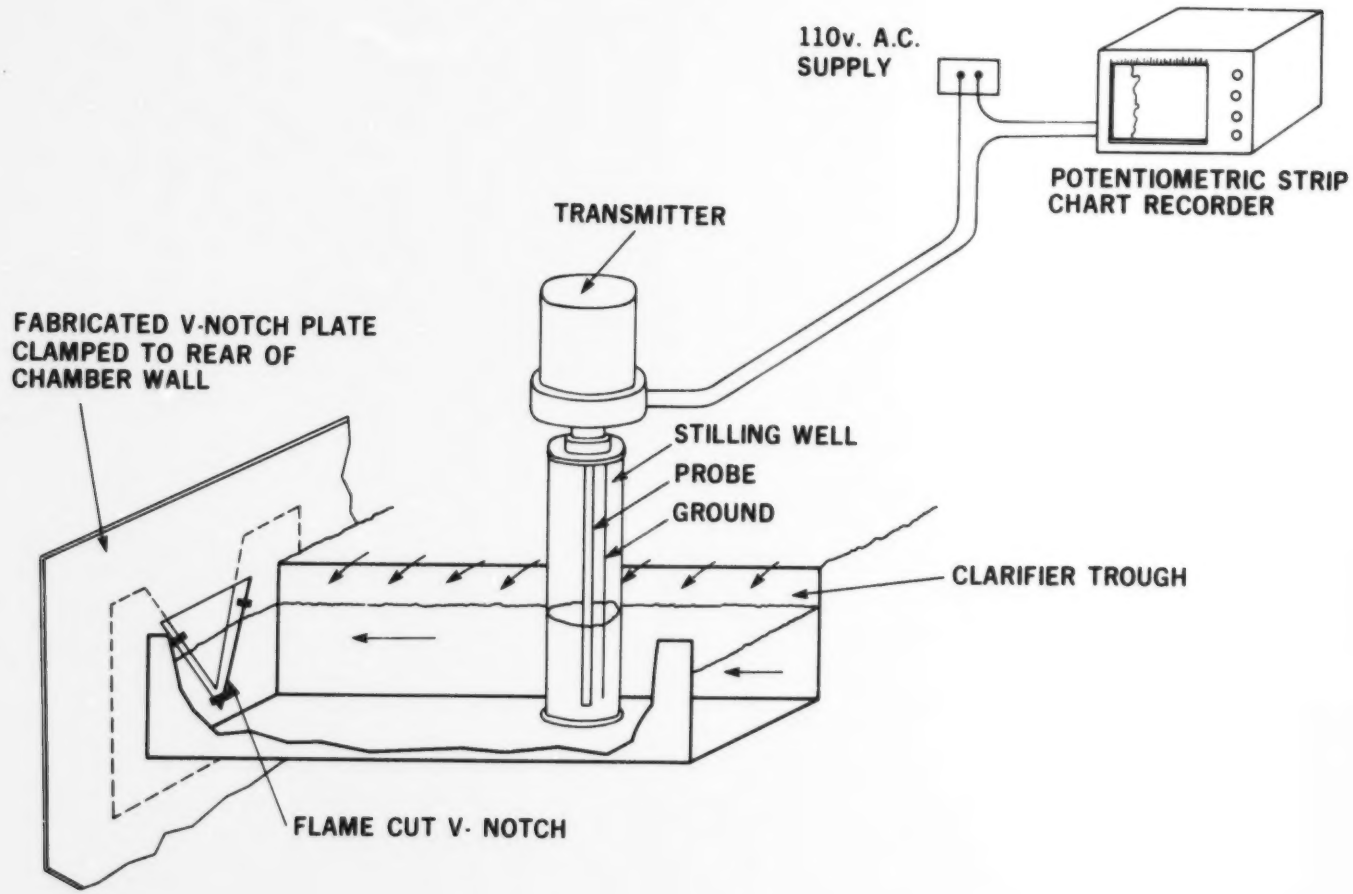


FIGURE 2-1 FLOW RECORDING BY ELECTRONIC TRANSMITTER

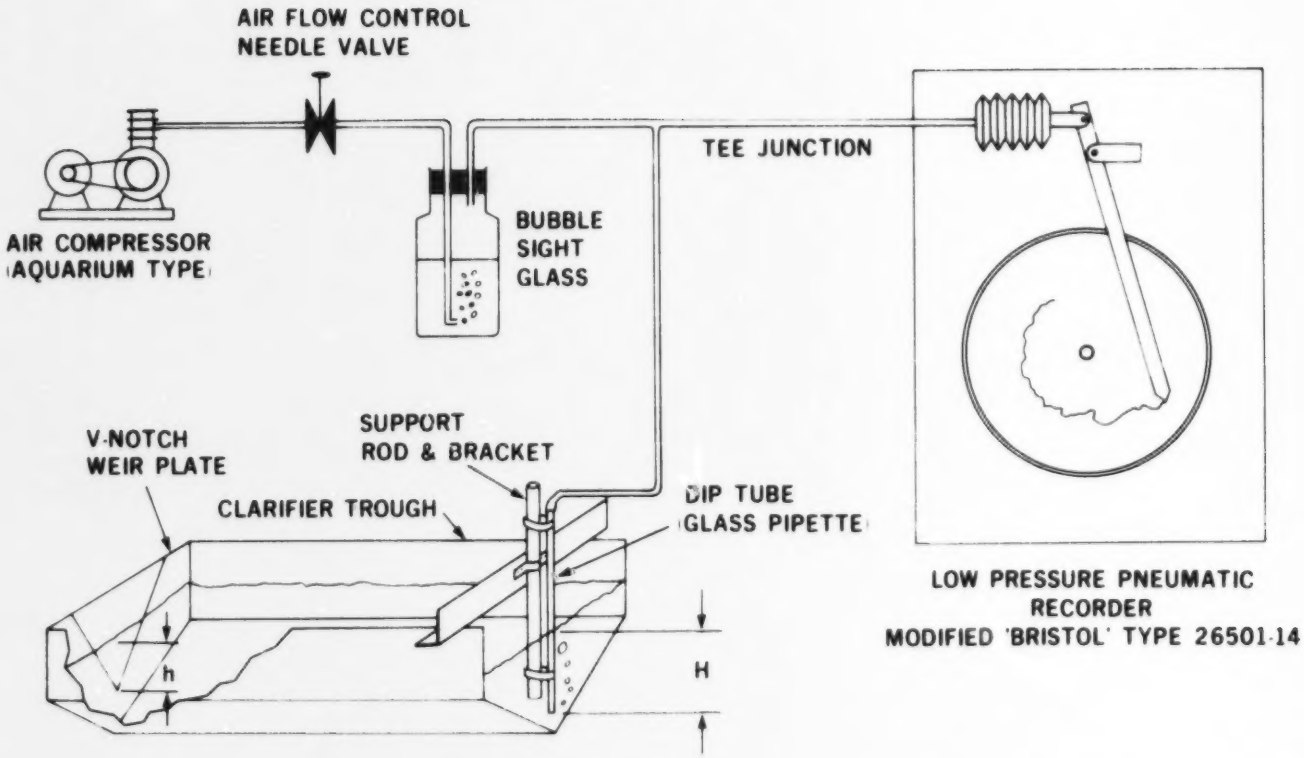


FIGURE 2-2 PNEUMATIC FLOW RECORDING APPARATUS

changes in water flow over the weir cause fluctuations in water level, which in turn induce capacitance changes in the electrode system located in the stilling well. The changes can be detected electronically and recorded on a potentiometric strip-chart recorder.

The weir boxes used were fabricated from 0.6 cm aluminum alloy plate and fitted with baffles, levelling screws, and a removable 22 1/2° V-notch weir. Three of the boxes were about 90 cm long, 43 cm wide and 45 cm deep. A smaller unit (90 cm x 30 cm x 30 cm) was also used.

Stilling wells, fabricated from polymethyl methacrylate 0.6 cm thick, 36 cm long, and from 7.5 cm to 10 cm in diameter, were located in the weir boxes. They served the dual purpose of modifying fluctuations in the head of water caused by external forces such as wind-induced wave action, and supporting the transmitter and level probe. Inside each stilling well cylinder, one electrode was maintained at ground potential and the other, sheathed in polytetrafluoroethylene, carried the A.C. sensing potential. The capacitance of each system (which varied with the depth of water) was measured by a Robertshaw Controls Company (Anaheim, California) "Level-Tel" unit. Three of these units (Model 157B1) operated from 110 volt A.C. and the other (Model 157B2) was powered by a 24-volt battery. The outputs from these measuring units were recorded on potentiometric strip-chart recorders.

2.4.1.2 Pneumatic system. This system (Figure 2-2) consists of a weir box, a bubbler and a recorder capable of measuring small changes in pressure. The bubbler, a 1-mL laboratory glass pipette, is located in the weir box as shown in the diagram and supplied with air by a small aquarium-type compressor. The pressure of the system was measured and recorded by a Bristol Company (Waterbury, Connecticut) pneumatic recorder - Model 2G501-14. The head of water passing over the weir is proportional to water flow; the higher the head of water above the bubbler outlet the higher will be the air pressure within the system.

2.4.2 Procedure. Five plants (1, 2, 8, 15 and 17) already had simple flow measurement devices built into the systems. They consisted of a 90° V-notch plate and it was generally found necessary to seal the outer edges of the plate to the sides of the water channel to obtain proper operation. In some instances, the existing weir plate was considered to be too crudely formed for use and on these occasions it was replaced by an accurately formed aluminum V-notch. The stilling well and capacitance level monitoring assembly were normally clamped to a baffle plate on the rear of the weir plate and adjusted so that the chosen zero point was level with the invert of the weir.

In eight of the plants (4, 6, 9, 10, 12, 18, 19 and 20) the only position in which a weir plate could be fitted was at the exit end of the clarifier trough. This allowed the fluid to back up in the trough and provided the necessary head on the weir. To measure this head, the stilling well and electronic assembly were simply placed in the trough and clamped to the side. In two of these plants (6 and 18) the shape of the trough precluded the use of the electronic transmitter. The pneumatic recorder, modified to increase the sensitivity to a maximum, was used instead.

In four of the plants (3, 5, 13, and 16) there was sufficient fall and space from the inlet to the chlorine contact tank to fit a fabricated plywood weir box. The side of this weir box was cut to fit snugly around the effluent pipe. The stilling well was then clamped to the outside of the box and connected to it with a short piece of plastic tubing.

The aluminum weir boxes described earlier were installed in plants 7, 11 and 14, where there was sufficient drop in the liquid level to accommodate them.

2.4.3 Flow Computations. Effluent flow rates were calculated by the following formula (5):

$$Q = 2.5 \tan\left(\frac{\theta}{2}\right) H^{2.5}$$

where Q = flow rate of effluent in cfs,
θ = angle of the V-notch in degrees, and
H = total head in feet.

Flow rates were later converted to m^3/d.

Approach velocities were consistently low and the corresponding velocity heads were negligible in all the plants. Static heads were measured manually from recording charts for every 12-minute interval and converted to corresponding flow rates.

While the procedure for flow computation was similar for 18 of the 20 sites, plants 13 and 14 required a different method of calculation. These two plants were installed side by side and operated in parallel from a common influent pipe fitted with an adjustable flow dividing chamber. A small proportion of the influent flows to the plants by gravity, but the bulk of it is pumped in. The pumps are controlled by float switches in the collecting sump. They run for a very short proportion of the total cycle, despite being fitted with a recirculating bypass. The intermittent nature of the flow and its very high

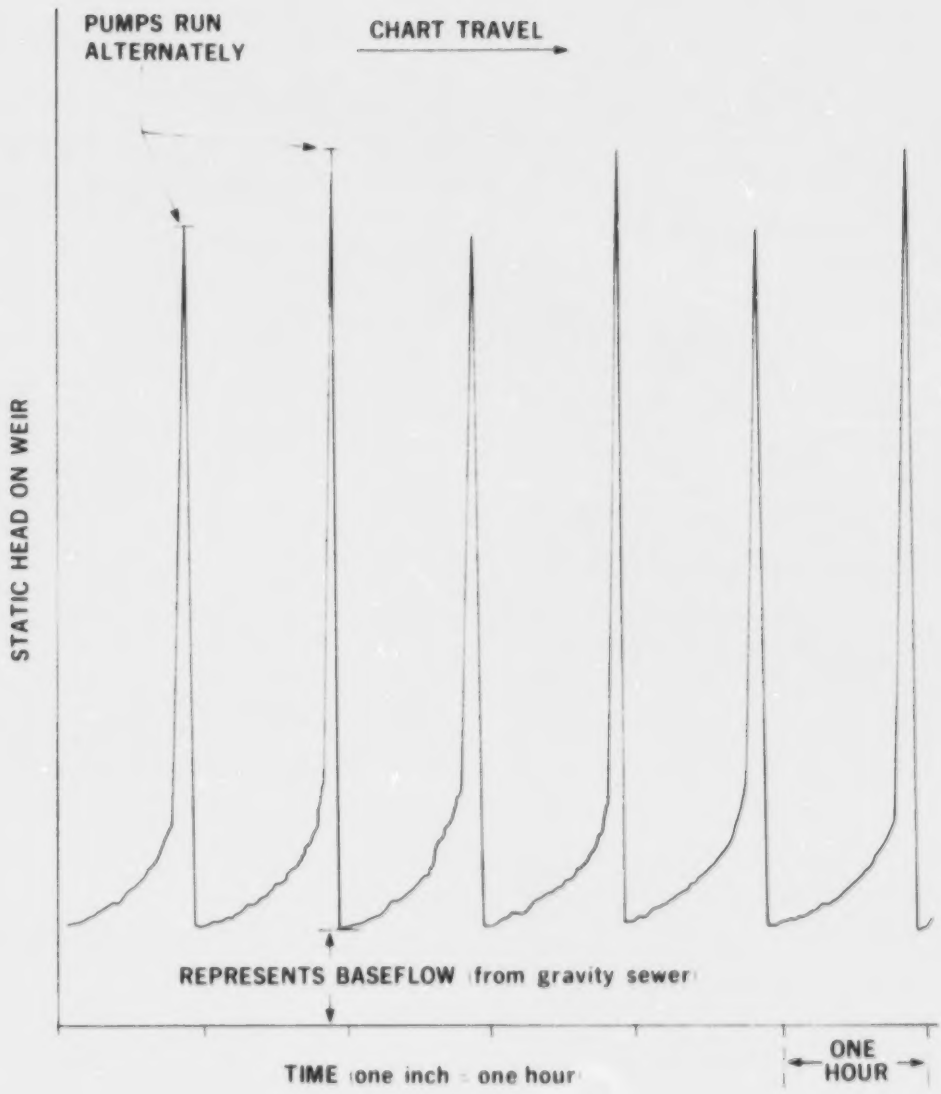


FIGURE 2-3 TYPICAL CURVE SHOWING PEAK FLOW RATES IN PLANTS 13 AND 14

peaks (see Figure 2-3) made interpretation of the flow charts extremely difficult. The measurement of head at 12-minute intervals was, therefore, considered inadequate.

As a result, it was decided to compute flow as a daily average. To do this, the number of pumping cycles each day (from the charts) were counted, the dimensions of the pump sump (and float settlings) were measured, and an allowance then made for the flow from the gravity-fed section (from the baseline shown in Figure 2-3).

3 PRESENTATION OF RESULTS AND ASSESSMENT OF PLANT PERFORMANCE

In this section of the report, the results of the test program conducted for the 20 Nova Scotian package plants are summarized and the salient features of these data are discussed. Qualitative parameters (i.e., effluent quality, pH data, clarifier performance) are examined in view of an assessment of overall package plant performance. Deficiencies in package plant performance are described and potential solutions to these problems examined. The cost factors involved in operation of package plants are assessed in the concluding section of this chapter.

3.1 Data Obtained

The operating data for the 20 Nova Scotian package plants are summarized in Table 3-1. The design parameters (daily flow rate, influent BOD_5, detention times and clarifier overflow rates) were obtained during interviews either with plant owners, suppliers or manufacturers. The actual values are the arithmetic means of all values obtained during the plant studies. Hydrographs showing daily values for maximum, average and minimum flows for each plant may be obtained by writing to the address on the inside front cover of this report. Maximum and minimum flows are the instantaneous values recorded each day; the daily average flow is the arithmetic mean of the flow rates recorded, taken at twelve minute intervals (Section 2.4.3).

The performance data for the 20 plants are summarized in Table 3-2. These data are derived from the large number of measurements carried out over the individual plant test periods. Two plants, 10 and 11, could not be compared to the NSF studies as they were made by manufacturers whose units were not tested by the NSF. Two other plants, 13 and 14, treated wastewater consisting mostly of laboratory wastes (Section 3.2.6), a type of wastewater not investigated in the NSF study.

In order to put the information presented in Table 3-1 into perspective, and to facilitate discussion of plant performance presented in subsequent sections of this report, normal ranges of design parameters reported for extended aeration plant operation are presented in Table 3-3.

3.2 Discussion of Data

3.2.1 Loading Patterns. The average hydraulic and organic loadings (Table 3-1) for the 20 plants are compared with their corresponding design values in Table 3-4. If the

TABLE 3-1 OPERATING DATA

Plant		Daily Flow Rate			Influent	Aeration Tank			Clarifier		
		Maximum m^3/d	Average m^3/d	Minimum m^3/d	BOD_5 kg/d	F/M Ratio kg BOD_5/kg MLSS•d	MLSS mg/L	Detention Time h	Overflow Rate $m^3/m^2 \cdot d$	Solids Loading $kg/m^2 \cdot d$	Detention Time h
1	Design	-	94	-	22.7	-	-	24	5	-	14
	Actual	286	147	82	14.8	0.32	476	15	8	4	9
2	Design	-	117	-	28.2	-	-	24	5	-	14
	Actual	118	80	60	14.3	0.05	2428	35	3	7	20
3	Design	-	29	-	9.1	-	-	32	10	-	7
	Actual	40	26	12	1.3	0.01	3347	36	9	30	8
4	Design	-	30	-	7.3	-	-	24	7	-	9
	Actual	10	8	5	0.9	0.006	4782	90	2	10	34
5	Design	-	57	-	18.2	-	-	27	10	-	7
	Actual	362	136	64	17.4	2.11	125	11	24	3	3
6	Design	-	57	-	18.2	-	-	27	10	-	7
	Actual	157	111	66	15.9	1.54	156	14	19	3	4
7	Design	-	49	-	15.7	-	-	27	8	-	18
	Actual	16	8	6	0.9	0.078	207	165	1	0.2	110
8	Design	-	14	-	2.8	-	-	31	6	-	10
	Actual	15	11	5	0.9	0.027	1879	39	5	9	13
9	Design	-	76	-	15.0	-	-	24	11	-	6
	Actual	82	48	38	14.1	0.314	577	38	7	4	9
10	Design	-	454	-	90.9	-	-	21	10	-	8
	Actual	253	173	142	46.8	0.022	5306	55	4	21	21

TABLE 3-1 OPERATING DATA (cont'd)

Plant		Daily Flow Rate			Influent	Aeration Tank			Clarifier		
		Maximum m^3/d	Average m^3/d	Minimum m^3/d	BOD_5 kg/d	F/M Ratio kg BOD_5/kg MLSS•d	MLSS mg/L	Detention Time h	Overflow Rate $m^3/m^2 \cdot d$	Solids Loading $kg/m^2 \cdot d$	Detention Time h
11	Design	-	15	-	N/A	-	-	N/A	7	-	N/A
	Actual	9	6	2	1.5	N/A	280	-	3	1	N/A
12	Design	-	85	-	27.3	-	-	24	12	-	5
	Actual	85	64	52	15.5	0.044	4134	34	1	4	7.1
13	Design	-	57	-	19.1	-	-	26	8	-	9
	Actual	69	40	2	1.6	0.03	992	35	6	6	13
14	Design	-	47	-	11.4	-	-	34	7	-	11
	Actual	50	29	2	1.3	0.015	1250	55	5	6	18
15	Design	-	19	-	4.5	-	-	29	4	-	5
	Actual	22	10	4	1.3	0.012	4341	55	2	9	9
16	Design	-	8	-	1.8	-	-	27	2	-	29
	Actual	10	5	2	0.4	0.017	2707	43	1	3	46
17	Design	-	341	-	81.8	-	-	28	10	-	7
	Actual	182	137	114	42.3	0.040	2595	70	4	10	17
18	Design	-	57	-	18.2	-	-	27	10	-	7
	Actual	159	84	27	10.4	0.057	2818	18	15	42	5
19	Design	-	38	-	7.7	-	-	28	10	-	7
	Actual	5	3	2	0.2	0.0016	3011	355	1	3	89
20	Design	-	24	-	4.5	-	-	36	7	-	10
	Actual	14	7	4	1.4	0.016	3410	123	2	7	34

N/A - Not Available

TABLE 3-2 SUMMARY OF PERFORMANCE DATA

		Mixed Liquor					Influent		Effluent		
Plant	Data Analysis	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Suspended Solids (mg/L)	Sludge Volume Index (mg/L)	Suspended Solids (mg/L)	BOD_5 (mg/L)	Suspended Solids (mg/L)	BOD_5 (mg/L)	Flow Rate (m^3/d)
1	Range	14.0-18.2	2.0-10.2	6.2-7.2	138-1172	37-304	14-145	35-253	14-514	17-150	82-286
	Arith. Mean	16.7	5.7	7.0	476	140	40	101	137	53	147
2	Range	13.5-18.8	0.4-5.5	5.3-6.7	1770-3705	41-92	32-107	78-243	5-178	5-43	60-118
	Arith. Mean	17.1	1.3	6.1	2428	68	65	178	22	15	80
3	Range	13.8-19.2	5.3-10.6	4.5-6.0	2545-5925	32-71	0.3-38	2-203	14-50	3-37	12-40
	Arith. Mean	16.3	9.4	5.2	3347	55	13	50	39	13	26
4	Range	14.5-19.0	0.5-10.4	5.2-6.7	2060-6454	43-74	2-89	7-276	7-51	8-30	5-10
	Arith. Mean	16.5	4.4	6.0	4782	58	30	113	22	16	8
5	Range	15.0-18.0	1.9-9.4	7.1-7.6	38-155	-	15-103	34-199	25-160	44-189	64-362
	Arith. Mean	17.8	6.4	7.3	125	-	40	128	74	110	136
6	Range	15.0-18.0	7.5-9.5	7.4-7.8	39-436	-	15-148	43-205	22-236	43-324	66-157
	Arith. Mean	18.1	8.8	7.6	156	-	67	142	90	111	111
7	Range	15.0-18.2	0.4-9.3	7.1-7.8	56-904	-	34-124	59-208	38-106	33-124	6-16
	Arith. Mean	16.6	4.3	7.4	207	-	61	111	62	69	8
8	Range	14.0-17.0	0.2-8.9	6.4-6.9	559-2566	237-921	11-63	25-226	6-150	6-72	5-15
	Arith. Mean	15.5	2.7	6.6	1879	398	31	82	31	23	11

TABLE 3-2 SUMMARY OF PERFORMANCE DATA (Cont'd)

		Mixed Liquor					Influent		Effluent		
Plant	Data Analysis	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Suspended Solids (mg/L)	Sludge Volume Index (mg/L)	Suspended Solids (mg/L)	BOD_5 (mg/L)	Suspended Solids (mg/L)	BOD_5 (mg/L)	Flow Rate (m^3/d)
9	Range	16.0-19.5	0.2-7.8	4.3-7.0	173-2986	26-41	18-242	123-647	26-554	18-496	38-82
	Arith. Mean	17.7	3.7	4.8	577	34	116	291	169	131	48
10	Range	18.5-21.5	0.4-1.6	6.7-7.1	4594-5804	52-73	107-327	148-490	6-164	2-45	142-253
	Arith. Mean	19.7	0.6	6.9	5306	62.0	167	271	24	11.0	173
11	Range	16.2-19.4	0.2-4.0	7.3-7.6	162-811	-	38-235	80-401	45-648	179-450	2-9
	Arith. Mean	18.3	1.8	7.4	280	-	95	256	221	299	6
12	Range	16.2-18.0	1.4-6.0	5.4-7.3	3432-4962	60-82	35-185	90-500	13-598	4-190	52-85
	Arith. Mean	16.9	4.0	5.9	4134	71	96	240	78	42	64
13	Range	18.8-20.8	3.2-8.0	4.9-6.8	277-1215	38-119	5-266	8-197	9-360	5-128	2-69
	Arith. Mean	19.6	6.2	5.0	992	86	32	45	60	25	40
14	Range	18.2-20.5	4.0-9.3	4.3-6.8	522-1605	45-96	5-266	8-197	7-47	1-27	2-50
	Arith. Mean	19.8	7.3	4.8	1250	64	32	45	19	9	29
15	Range	18.2-20.8	0.2-5.4	6.9-7.3	2320-5284	103-252	11-124	75-217	5-244	4-88	4-22
	Arith. Mean	19.2	0.6	7.1	4341	157	45	127	39	17	10
16	Range	17.0-21.2	0.2-9.1	4.1-6.8	24-4650	49-90	7-62	3-140	15-81	3-13	2-10
	Arith. Mean	19.2	5.1	4.7	2707	63	31	84	34.0	7	5

TABLE 3-2 SUMMARY OF PERFORMANCE DATA (Cont'd)

		Mixed Liquor					Influent		Effluent		
Plant	Data Analysis	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Suspended Solids (mg/L)	Sludge Volume Index (mg/L)	Suspended Solids (mg/L)	BOD_5 (mg/L)	Suspended Solids (mg/L)	BOD_5 (mg/L)	Flow Rate (m^3/d)
17	Range	18.0-21.0	0.65-3.3	6.7-7.0	2195-2998	122-366	15-346	144-640	21-648	7-137	114-182
	Arith. Mean	19.3	1.7	6.9	2595	229	144	309	126	28	137
18	Range	15.5-19	5.5-9.0	6.0-7.2	2056-3786	57-83	2-133	4-370	14-217	13-65	27-159
	Arith. Mean	17.4	7.3	6.3	2818	69	50	126	106	34	84
19	Range	16.2-18.5	3.4-10.4	4.2-7.0	2444-3436	45-57	3-118	2-360	44-101	1-95	2-5
	Arith. Mean	17.8	7.1	4.7	3011	51	34	72	68	14	3
20	Range	15-16.5	0.3-2.7	4.5-7.1	142-4720	70-117	3-143	3-620	5-221	14-174	4-14
	Arith. Mean	15.5	0.7	6.4	3410	89	61	212	44	58	7

TABLE 3-3 NORMAL RANGES OF DESIGN PARAMETERS FOR EXTENDED AERATION PLANTS (6-11)

Design Parameter	Range
Aeration Tank	
Organic Loading (kg BOD_5/kg MLSS•d)	0.05 to 0.1
MLSS (mg/L)	3 000 to 6 000
Detention Time (h)	18 to 36
Clarifier	
Overflow Rate (m^3/m^2•d)	8 to 24
Solids Loading (kg/m^2•d)	30 to 60
Detention Time (h)	3 to 4

TABLE 3-4 HYDRAULIC AND ORGANIC LOADING PATTERNS

		Organic Load	
	Hydraulic Load	kg BOD_5/d*	F/M Ratio** kg BOD_5/kg MLSS•d
Number of plants in which the actual average load was within + 5% of the design value.	None	One (Plant 5)	Two (Plants 2 and 18)
Number of plants in which the average load was more than 105% of the design value.	Four (Plants 1, 5, 6 and 18)	None	None
Number of plants in which the average load was less than 95% of the design value.	Sixteen (Plants 2, 3 4, 7, 8, 9 10, 11, 12, 13 14, 15, 16, 17 19 and 20)	Eighteen (All plants except 5 and 11)	Nine (Plants 3, 4 10, 12, 15, 16 17, 19 and 20)

* kg BOD_5/d used in the design of plant 11 was not available and, therefore, plant 11 was not used in the comparison.

** Actual F/M ratios were compared to the normal range of F/M ratios for extended aeration systems (Table 3-3). Plants having an average MLSS less than 2000 mg/L were not included in the comparison.

assumption is made that average loads within ± 5 percent of the design loads represent normal operation, only four plants were hydraulically overloaded and none of those systems which were properly operated were organically overloaded. It should be noted that a number of plants had abnormally low MLSS values when compared with the generally accepted design values presented in Table 3-3. Too low a MLSS tends to be symptomatic of operational problems such as clogged sludge return lines or inappropriate sludge wasting. For this reason only plants having a MLSS greater than 2000 mg/L are included in Table 3-4 when comparing F/M ratios with the plants' design values.

Plants 5 and 6, which were operated by the same crew, and plant 18 were hydraulically overloaded during most of the test periods. Plant 1, which was essentially the same as plant 2 in that it was manufactured by the same company, operated by the same crew and served a similiar subdivision, was overloaded hydraulically because of infiltration problems more severe than those encountered in plant 2 and probable illegal surface water connections. The more severe infiltration problems were the result of a higher water table in the area served by plant 1.

The actual influent BOD_5 values show that all plants received influent lower in biological oxygen demand than their design values (Table 3-1). The only plants that were organically overloaded with respect to food-to-microorganism ratio (F/M, expressed as kg BOD_5/kg MLSS•d) were 5 and 6. These plants received BOD_5 loadings slightly below their design capacity; the abnormally high F/M ratios were probably due to low MLSS values occasioned by clogging of sludge return lines and, in the case of plant 5, an unusual sludge wasting carried out during the test period. Plants 2, 7 and 18 had organic loadings within the optimum range; however, in the case of plant 7 the biomass concentration (MLSS) was very low. The organic loading values for plants 1 and 9 were within the design range for a conventional activated sludge process, but the MLSS values were low. It should be remembered that, because of the sensitivity of F/M ratio to MLSS values, plants with abnormally low MLSS (<2000 mg/L) were not tabulated in Table 3-4.

3.2.2 Flow Variations. Ratios of maximum flow (Qmax) to average flow (Qave) and minimum flow (Qmin) to average flow are useful parameters in designing wastewater treatment plants. Empirically determined equations relating these ratios to the population (p, expressed in thousands) have been published (12):

$$\frac{Qmax}{Qave} = \frac{5}{p0.17} \qquad (A)$$

and

$$\frac{Qmin}{Qave} = 0.2\,p^{0.17} \qquad (B)$$

Variations in flow have been shown to be higher for smaller plants (9,12). The ratio between the maximum and average daily flow rates (peaking factor) is known to be high for small treatment plants and low for large plants (12).

In the following paragraphs, the peaking factor and the ratio Qmin/Qave have been related to Qave for the 11 plants (1, 2, 5, 6, 7, 9, 10, 11, 12, 15 and 17) serving subdivisions, trailer parks and housing quarters. Plants serving schools, an office, a research institute and a restaurant are not included in this category because such establishments obviously generate different patterns of flow. The actual population equivalents contributing to the plants at the time of the study were not available. Therefore, the measured average daily flow rates were used to represent p. For each plant, the two ratios (Qmax/Qave and Qmin/Qave) were calculated for days when flow data were available and the average of those ratios were plotted against Qave in a log-log graph, as shown in Figure 3-1. A straight line of best fit was drawn for each relationship by using the method of least squares. The equations of best fit for the 11 plants are:

$$\frac{Qmax}{Qave} = \frac{17}{(Qave)^{0.4}} \qquad (C)$$

$$\frac{Qmin}{Qave} = \frac{(Qave)^{0.22}}{8} \qquad (D)$$

where, Q is in m^3/d.

These equations can be converted to the forms published in the literature (12) by replacing Qave with p at the rate of 0.36 m^3/d of per-person wastewater flow rate. The resulting equations are:

$$\frac{Qmax}{Qave} = \frac{1.7}{p^{0.4}} \qquad (E)$$

$$\frac{Qmin}{Qave} = 0.45\,p^{0.22} \qquad (F)$$

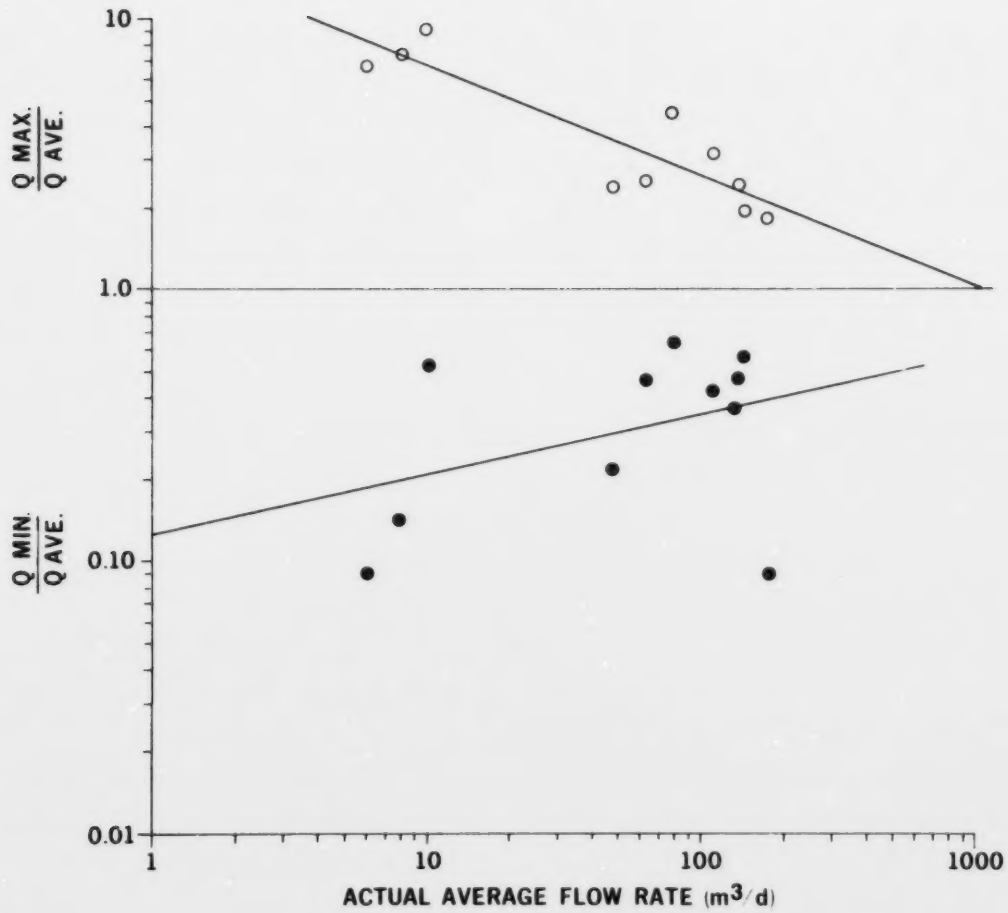


FIGURE 3-1 EFFLUENT FLOW VARIATIONS IN PACKAGE PLANTS OF SUBDIVISIONS AND TRAILER PARKS

These equations are of limited scope because they are based on limited data and, specifically, based on plants of design populations varying from a rather narrow range of about 20 to 1000. As shown in Figure 3-2, the straight lines of best fit representing equations (E) and (F) are compared to the corresponding lines proposed in the literature (12). While the similarity in trends is obvious between the published equations and equations (E) and (F), the relationships are only valid for plants being installed within the study area and serving a design population of less than 1000, or for an area having a similar quantity and quality of wastewater. The specific reasons for the differences between the published equations and the present equations cannot be explained with the limited quantity of data available.

3.2.3 Effluent Quality. The Province of Nova Scotia has set guidelines which state that the average BOD_5 and SS should not exceed 30 mg/L and 30 mg/L, respectively. The results of effluent quality measurements for the plants in this study are summarized graphically in Figure 3-3 (plant 11 does not appear as its average BOD_5 and SS levels were too high to be plotted on the graph). As an aid to the following discussion five classes of effluent were arbitrarily designated as shown in Figure 3-3: excellent, good, moderate, poor and extremely poor. The 45° degree line shows that in 15 plants average SS concentrations were higher than the corresponding BOD_5 levels. While the lower BOD_5 levels indicate a degree of effluent stabilization in most plants, relatively high effluent SS concentrations indicate loss of mineralized solids due to denitrification, septic sludge and clogging of sludge return systems.

Four plants (2, 4, 10 and 14) achieved excellent or good effluent quality, and an additional four plants (3, 8, 15 and 16) achieved a moderate effluent quality with BOD_5 levels lower than 30 mg/L (i.e., they met the 30 mg/L BOD_5 guideline). Although plant 2 was, as has already been mentioned, similiar to plant 1, it produced a good quality effluent which was comparable to that obtained in the NSF study, while plant 1's effluent was extremely poor. The sludge produced in plant 2 had excellent settling properties, whereas the hydraulic overloading of plant 1 and inadequate sludge return resulted in low MLSS concentrations and consequently unsatisfactory effluent. While the effluent quality of plant 4 was seemingly good, this may have been fortuitous as some solids were lost in sampling. Plant 10 received influent of normal strength and produced good quality effluent; a testimonial to good maintenance. In addition, the mixed liquor, pH, SS and SVI values were well within the normally acceptable ranges.

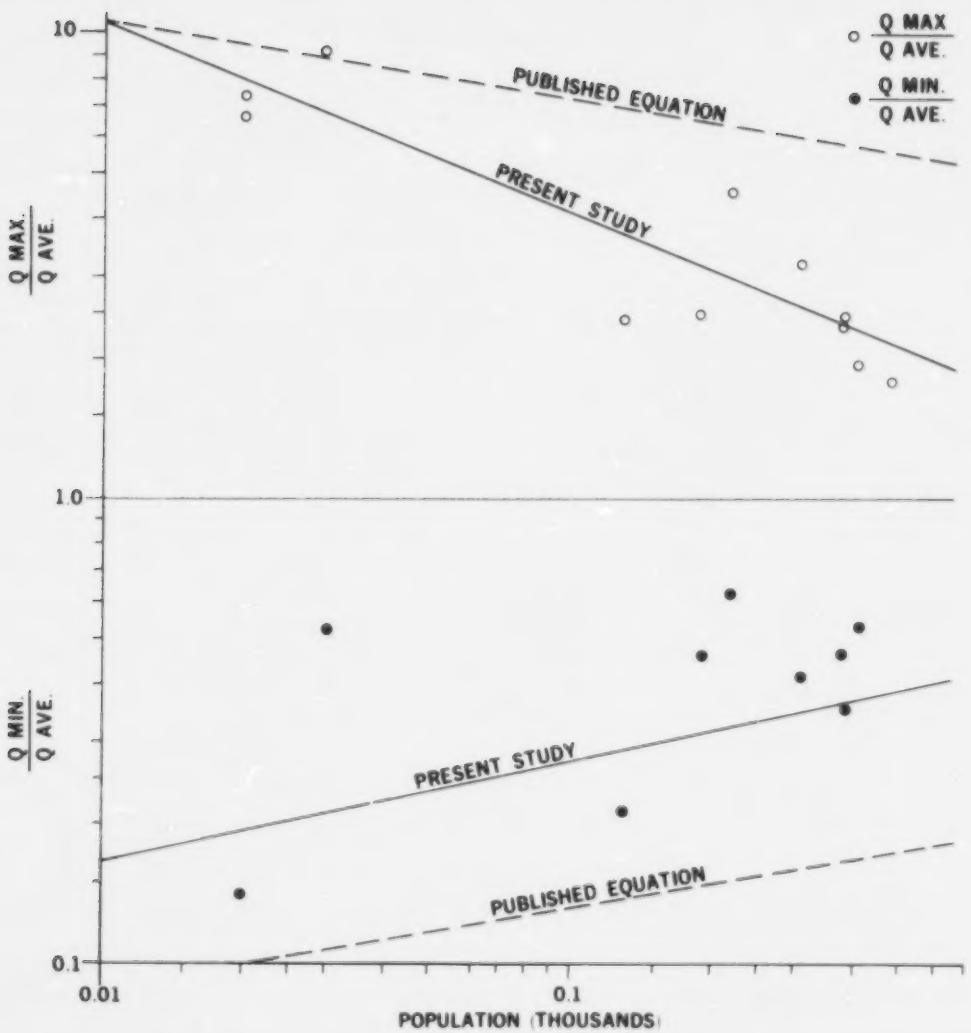


FIGURE 3-2 FLUCTUATIONS IN FLOW AS FUNCTIONS OF POPULATION EQUIVALENT

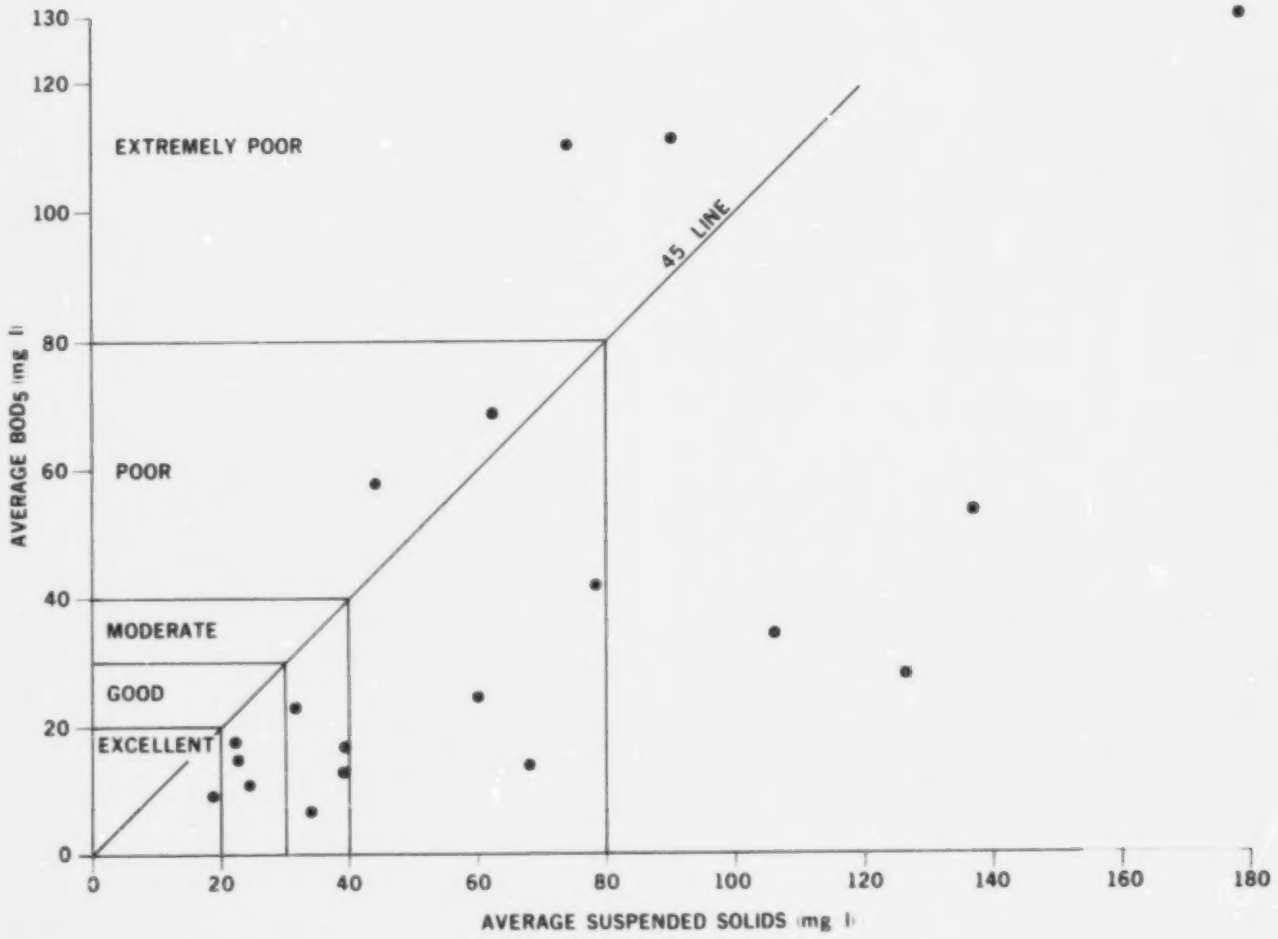


FIGURE 3-3 EFFLUENT QUALITY PARAMETERS (AVERAGES) OF INDIVIDUAL PLANTS

The majority of plants, however, produced effluents of unacceptable quality. This is in contrast to the results obtained from similiar plants in the NSF study, where median BOD_5 levels ranged from 4 to 24 mg/L and the corresponding SS concentrations from 9 to 26 mg/L. It should also be noted that the average of the eight median effluent BOD_5 values of the NSF plants was 12 mg/L and the corresponding SS concentration was 16 mg/L, indicating that the trend in NSF plants was similiar to that observed in this study; namely, effluent SS concentrations were higher in magnitude than BOD_5 levels.

Effluent quality data from the 16 plants of this investigation that were analogous to those in the NSF study are compared to NSF quality data in Table 3-5. The results show that in terms of SS, 15 out of 16 plants did not attain their potential. In terms of effluent BOD_5, 13 out of the 16 plants were unable to achieve their potential. None of the plants discharged an effluent having both BOD_5 and SS equal to or less than concentrations achieved by NSF plants. The reasons for the poor showing of the Nova Scotian plants were numerous and differed in almost every case. They are summarized and discussed in Section 3.4.

TABLE 3-5 COMPARISON OF EFFLUENT QUALITY WITH THAT OF THE NSF STUDY

Plant	Effluent SS Higher Than NSF Study	Effluent SS Comparable to the NSF Study	Effluent SS Lower Than NSF Study	Effluent BOD_5 Higher Than NSF Study	Effluent BOD_5 Comparable to the NSF Study	Effluent BOD_5 Less Than NSF Study
1	x			x		
2		x		x		
3	x					x
4	x			x		
5	x			x		
6	x			x		
7	x			x		
8	x			x		
9	x			x		
12	x			x		
15	x			x		
16	x					x
17	x			x		
18	x			x		
19	x					x
20	x			x		
Total	Fifteen	One	-	Thirteen	-	Three

It should be noted that five of the plants that were both hydraulically and organically underloaded (plants 3, 4, 12, 16 and 19) were, in all probability, undergoing nitrification/denitrification, which could have been the reason for the higher effluent SS concentrations from these plants. These plants were characterized by high and/or highly fluctuating DO, an initially low pH or a drop in pH, low F/M ratios and long aeration tank detention times.

3.2.4 pH Data. The pH values for the 20 Nova Scotian package plants are presented in Table 3-6, which shows that a number of influent, effluent and mixed liquor samples were characterized by an unusually low range of pH values. For instance, the mean pH of the influent was below 6 for plants 9 and 16. Plant 9 serves a trailer park that obtains its water supply from a normally acidic lake. Raw water pH of the lake ranged from 3.4 to 3.9 during a study in 1973 (13). Plant 16 serves an office building that obtains its water from a shallow well; the normal pH of the treated water was 6.2. Numerous Nova Scotian lakes are characterized by acidic and corrosive waters of very low buffering capacity (i.e., low alkalinity) (14), a fact to which the lower pH values of some influent samples may be attributed. In plants 3, 12, 13, 14 and 19 the mean effluent pH levels were considerably lower than in their corresponding influents. Such drops in pH are the result of nitrification, a process which produces hydrogen ions (15,16). McCarty and Broderson reported that in one experiment nitrification decreased the mixed liquor pH to 4.5 (12). The problem is more pronounced in soft water areas where there is little residual alkalinity present to buffer hydrogen ion production (15).

3.2.5 Clarifier Performance. The operating data for clarifier parameters (overflow rate, solids loading and detention time) are given in Table 3-1. When these data are compared to the design values, it may be seen that most of the clarifiers were underloaded in terms of overflow rate and solids loading. Fifteen plants had overflow rates below the specified range of 8 to 24 $m^3/m^2 \cdot d$; the remaining five were within the range specified. Seventeen plants had solids loading values below the design range of 30 to 60 $kg/m^2 \cdot d$, (Table 3-3); three plants were within the specified range. Seventeen plants had clarifier detention times in excess of the normally recommended three to four hours. Long clarifier detention times combined with inadequate sludge return facilities may result in septic sludges that eventually float to the clarifier surface. Carbon dioxide produced by anaerobic decomposition of sludge, or nitrogen gas produced by denitrification, is entrapped within the sludge floc particles lifting the sludge blanket to

TABLE 3-6 pH RANGES OF SAMPLES

Plant	Influent		Effluent		Mixed Liquor	
	Range	Mean*	Range	Mean*	Range	Mean*
1	6.9 to 7.2	7.1	-	-	6.2 to 7.2	7.0
2	6.9 to 7.5	7.2	-	-	5.3 to 6.7	6.1
3	5.9 to 8.5	6.7	5.6 to 6.2	5.8	4.5 to 6.0	5.2
4	5.5 to 7.7	6.5	6.7	6.7	5.2 to 6.7	6.0
5	-	-	-	-	7.1 to 7.6	7.3
6	-	-	-	-	7.4 to 7.8	7.6
7	-	-	-	-	7.1 to 7.8	7.4
8	-	-	-	-	6.4 to 6.9	6.6
9	4.7 to 5.6	5.1	4.8 to 6.0	4.9	4.3 to 7.0	4.8
10	-	-	-	-	6.7 to 7.1	6.9
11	-	-	-	-	7.3 to 7.6	7.4
12	7.2 to 7.5	7.3	5.3 to 5.6	5.4	5.4 to 7.3	5.9
13	6.7 to 8.7	7.4	5.0 to 6.1	5.5	4.9 to 6.8	5.0
14	6.7 to 8.7	7.4	4.8 to 6.6	5.3	4.3 to 6.8	4.8
15	-	-	-	-	6.9 to 7.3	7.1
16	4.4 to 8.5	5.1	4.1 to 8.5	4.6	4.1 to 6.8	4.7
17	-	-	-	-	6.7 to 7.0	6.9
18	-	-	-	-	6.0 to 7.2	6.3
19	7.3 to 8.2	7.7	4.2 to 6.0	4.5	4.2 to 7.0	4.7
20	-	-	-	-	4.5 to 7.1	6.4

* Mean pH value was calculated by taking into account the fact that pH = - log H. Thus, mean pH of 'N' number of observations (pH_1, pH_2, pH_3, ------ pH_n) is the negative logarithm of ($H_1 + H_2 + H_3$ ------ H_n)/n.

the clarifier surface. Either phenomenon can result in loss of large quantities of SS over the weir of the clarifier.

3.2.6 Comparison of Plants 13 and 14. Plants 13 and 14, located side by side, treated laboratory wastewater from a research institute engaged in marine research and pollution studies. They were manufactured by two different companies. Because they treated identical wastewater, an opportunity existed to relate the performance of one unit with the other. A flow splitting box in the influent pipe diverted part of the flow to each plant; the proportions between the flow rates of plants 13 and 14 were almost always in the ratio of 1:0.73.

Plant 13 produced an effluent inferior to that of plant 14 because of lower MLSS in its aeration tank (due to clogging of the sludge return pipes, a problem which did

not exist in plant 14), and higher SVI values. In addition, the malfunctioning of the skimmer in plant 13 probably also contributed to its lower effluent quality.

The influent BOD_5 and SS concentrations were unusually low for plants 13 and 14 (Table 3-2). Because of this, it was decided to compare the influent data to the influent data collected in a study conducted by the Environmental Protection Service (EPS) Atlantic Region, Environment Canada. These data are summarized in Table 3-7. In the EPS survey (17), conducted in October, 1975, and July, 1976, samples were taken at the lift station which discharges most of the wastewater into plants 13 and 14. Twelve five-hour and one four-hour composite samples were collected in October, using a Sigmamotor sampler with a 3-mm internal diameter tube to which was attached a fibreglass screen with 1.5-mm openings. In July 1976, one 12-hour and four 23-hour samples were collected by a Carlton sampler with 3-mm internal diameter tubes fitted with a cage type screen with 6-mm diameter openings. The present study, conducted in August 1976, used 3-mm internal diameter sampling tubes fitted with screens with 1.5-mm diameter openings.

TABLE 3-7 COMPARISON OF INFLUENT QUALITY OF PLANTS 13 AND 14 OF THE PRESENT STUDY WITH AN EPS SURVEY

Experimental Details	EPS Study (17) Part I October 1975	EPS Study (17) Part II July 1976	Present Study August 1976
Sampling Tube Internal Diameter	3 mm	3 mm	3 mm
Screen Opening Size	1.5 mm	6 mm	1.5 mm
Sampling Location	Lift Station	Lift Station	The common influent sewer to the two plants.
Sampling Location Includes or Excludes Gravity Sewer	Excludes	Excludes	Includes
Mean Influent BOD_5 (mg/L)	112	216	45
Range of Influent BOD_5 (mg/L)	15 to 200	60 to 370	8 to 197
Mean Influent SS (mg/L)	102	183	32
Range of Influent SS (mg/L)	20 to 190	95 to 290	5 to 266
Compositing Periods	4 and 5 hours (8:30 to 13:30 and 13:30 to 18:30)	12 and 23 hours	24 hours

The sampling of influent in the EPS survey and the present study differed in location, time and period of sampling, and in the size of the screen openings used. The differences between average values of influent BOD_5 and SS found for the EPS study and for the present study were very wide. The author of this report is unable to explain with certainty the quality variations; however, it is thought reasonable to assume that the size of the screen attached to the end of the sampling tubes had an important bearing on the quality of the data and the representiveness of the influent samples. Note that in the EPS surveys higher BOD_5 and SS values were obtained in July when large screen openings were used. When comparing the influent data from the EPS survey with the present study, it should be noted that EPS samples were taken in the daytime when laboratories were in operation, while samples in the present study were taken over a 24-hour sampling period. In addition, the EPS samples did not include wastewater from the gravity sewer.

3.3 Operating Deficiencies and Potential Solutions

The deficiencies and problem areas identified at the 20 Nova Scotian package plants are summarized in Table 3-8. To facilitate an overall view, the problems are divided into three categories: general, process and equipment. For each problem identified, the number of plants affected and the plant identification numbers are listed.

Under the general category, category A, it is seen that nine plants had operators who lacked formal training; in the remaining 11 plants the operators had a "Level 1" training (see Appendix, Table A2), an introductory course in a three-part training series sponsored jointly by the provincial and federal Departments of the Environment (18). Field observations and personal judgement were the basis for the maintenance quality classifications.

Identification of process-oriented problems (category B) was based on interpretation of the operating and performance data (Tables 3-1 and 3-2). The requirement for sludge treatment facilities and provisions for ultimate disposal of sludges is an extremely important factor and was not dealt with in 13 of the 20 plants. Without provisions for sludge wasting, solids accumulate in the system and are eventually discharged over the weir of the clarifier. It is evident that this was occurring in many of the plants investigated and is likely the major cause of the high effluent SS.

Equipment-oriented problems (category C) were identified from interviews with plant owners, operators, manufacturers and others.

Deficiencies and problem areas considered to have a direct influence on effluent quality and potential solutions to them are given in Table 3-9. The package

TABLE 3-8 IDENTIFICATION OF DEFICIENCIES AND PROBLEM AREAS

Deficiencies and Problem Areas	Number of Plants	Plants
Category A. General		
Lack of operator training	Nine	1, 2, 5, 6, 9, 10, 11, 12, 20
Very poor maintenance	Four	5, 6, 9, 11
Poor maintenance	Four	1, 7, 12, 20
Category B. Process		
Sludge treatment and disposal facilities not provided	Thirteen	3, 4, 5, 6, 7, 9, 11, 12, 16, 17, 18, 19, 20
Inadequate biomass in aeration tank	Nine	1, 5, 6, 7, 8, 9, 11, 13, 14
Inadequate aeration	Seven	8, 9, 10, 11, 15, 17, 20
Low mixed liquor pH (below 6)	Seven	3, 9, 12, 13, 14, 16, 19
Nitrification/denitrification	Five	3, 4, 12, 16, 19
Sludge bulking	Four	1, 8, 15, 17
Offensive odour	Four	1, 5, 6, 9
Hydraulic overload	Four	1, 5, 6, 18
Highly fluctuating mixed liquor DO	Four	4, 7, 9, 16
Oil and/or grease in influent	Two	8, 20
Low influent pH (below 6)	Two	9, 16
Category C. Equipment		
Comminutor breakdown	Eleven	3, 4, 5, 6, 9, 12, 14, 15, 16, 17, 19
Clogging of air diffuser	Nine	1, 2, 4, 5, 6, 9, 17, 18, 20
Clogging of sludge return system	Nine	1, 2, 5, 6, 9, 13, 15, 16, 17
Clogging and freezing of chlorine feed line	Four	1, 2, 15, 16
Compressor (blower) breakdown	Three	3, 4, 12
Clogging and/or malfunctioning of skimmer	Two	8, 13
Formation of ice in clarifier in winter	Two	3, 20
Freezing of froth control spray nozzle	Two	1, 2
Rusting of steel tank	Two	18, 20
Malfunction of chlorinator pump	One	20
Rubber diaphragm check valve failure	One	14
Vibration in compressor foundation	One	10

TABLE 3-9 EFFLUENT QUALITY, PROBLEM AREAS AND POTENTIAL SOLUTIONS

Effluent Quality* (see Figure 3-1)	BOD_5 or SS Concentration (mg/L)*	Plant	Deficiencies and Problem Areas	Potential Solutions	Notes
Excellent	<20	14	LMLPH, IBM, HMLDO, HS	PHA, RA, INBM, FE	Note A - Potential solution to CSRS problem is discussed in Section 3.3.1 Note B - Hydraulic overloading in plant 1 can be solved by eliminating illegal sewer connections, and infiltration. Note C - Sludge wasted from aeration tank two to three times per year; this not likely to be adequate.
Good	21 to 30	2	CSRS, LOT, CD	See Note A, OT, IM	
"	"	4	ND, CD, HFMLDO, HMLDO	RA, PHA, PSTDF	
"	"	10	IA	INA, See Note C	
Moderate	31 to 40	3	ND, LMLPH, HMLDO	RA, PHA PSTDF	
"	"	8	SB, IBM, IA, CS, oily chemicals in influent	ROG, INA, INBM	
"	"	15	SB, IA, CSRS	INA, See Note A	
"	"	16	LMLPH, CSRS, HFMLDO, HFMLSS, LIPH, ND, IBM	PHA, See Note A, PSTDF	
Poor	41 to 80	7	IBM, PM, HFMLDO	IM, INBM, OT, PSTDF	
"	"	12	ND, LMLPH, LOT, PM	PHA, IM, OT, PSTDF	
"	"	13	IBM, CSRS, LMLPH, HMLDO, CS, HS	PHA, RA, See note A, FE	
"	"	19	ND, LMLPH, HMLDO	RA, PSTDF	
"	"	20	IA, Grease in influent, PM, LOT,CD	INA, ROG, See Note A, IM, PSTDF	
Extremely Poor	>80	1	HOL, Chronic CSRS, IBM, CD, OO, HFMR, SB, PM, LOT	FE, See Notes A and B, IM, INBM, OT	
"	"	5	HOL, HFMR, VPM, CSRS, OO, CD, LOT, IBM, HMLDO	FE, IM, See Note A, OT, INBM, PSTDF	
"	"	6	HOL, HFMR, VPM, CSRS, OO, CD, LOT, IBM, HMLDO	FE, IM, See Note A, OT, INBM, PSTDF	
"	"	9	HFMR, VPM, CSRS, OO, CD, LOT, IBM, LIPH, LMLPH, HFMLDO	IM, PHA, OT, INBM, See Note A, PSTDF	
"	"	11	IBM, VPM, LOT, Insufficient data to evaluate fully	IM, OT, INBM, PSTDF	
"	"	17	SB, CSRS, CD, IA on some days	See Note A, INA, PSTDF	
"	"	18	HOL, CD	FE, PSTDF	

*The higher of the two concentrations is taken into consideration in designating the effluent quality.

ABBREVIATIONS

CD	-	Clogging of diffusers.
CS	-	Clogging and/or malfunctioning of skimmer
CSRS	-	Clogging of sludge return system
FE	-	Flow equalization
HFMLDO	-	Highly fluctuating mixed liquor DO
HFMLSS	-	Highly fluctuating mixed liquor SS
HFMR	-	High F/M ratio
HMLDO	-	High mixed liquor DO
HOL	-	Hydraulic overload
HS	-	Clarifier subjected to hydraulic surges
IA	-	Inadequate aeration
IBM	-	Inadequate biomass in aeration tank
IM	-	Improve maintenance
INBM	-	Increase biomass in aeration tank
INA	-	Increase aeration (time or intensity).
LIPH	-	Low influent pH.
LMLPH	-	Low mixed liquor pH.
LOT	-	Lack of operator training.
ND	-	Potential nitrification/denitrification problem.
OO	-	Offensive odour.
OT	-	Operator training.
PHA	-	pH adjustment (alkalinity addition for nitrification).
PM	-	Poor maintenance.
PSTDF	-	Provide sludge treatment and disposal facilities.
RA	-	Reduce aeration (time or intensity).
ROG	-	Remove oil and grease before wastewater enters aeration tank.
SB	-	Sludge bulking.
VPM	-	Very poor maintenance.

plants are listed in order of the effluent quality achieved. Deficiencies, problem areas and potential solutions for each plant are abbreviated; abbreviations are identified at the end of the table. For example, plant 14, which produced excellent effluent quality, had problems identified as: low mixed liquor pH (LMLPH), inadequate biomass in aeration tank (IBM) and highly fluctuating mixed liquor dissolved oxygen (HMLDO). The potential solutions to these problems are pH adjustment - alkalinity addition for nitrification (PHA), and reduced aeration time or intensity (RA).

It should be noted that in the case of mixed liquor DO, values from 1 to 3 mg/L were considered to be within the optimum range (based on the work of Smith and Given, reference 7). Values less than 1 mg/L would provide insufficient aeration; values between 3 and 5 mg/L would require an excessive amount of energy; and values above 5 mg/L would be uneconomical. The condition designated as "highly fluctuating mixed liquor DO" occurred when the DO value was below 1 mg/L for at least two days of the test period and was above 5 mg/L for at least two other days of the test period.

3.3.1 Biomass Level and Clogging of Sludge Return Lines. Nine plants had insufficient biomass in the aeration tanks. The probable reasons for this condition are summarized in Table 3-10. The primary cause of low biomass seems to be the frequent clogging of sludge return systems; hydraulic shock loading seems to be the secondary cause of inadequate biomass levels. All nine plants reported frequent clogging of the sludge return lines and in five of these plants the average MLSS was below 2000 mg/L. Plant 16 (not included in Table 3-10 as its average MLSS was 2700 mg/L) experienced clogging of the sludge return line and when this occurred, MLSS values of less than 100 mg/L were recorded. Three of the four plants subject to hydraulic overloading (see Table 3-4) had average MLSS values below 2000 mg/L, probably because solids could not be retained within the treatment system. Flow equalization would reduce or eliminate problems associated with hydraulic overloading.

Besides resulting in the inability of a plant to maintain adequate MLSS levels, clogging of a sludge return system also results in an accumulation of solids in the clarifier, an increase of F/M ratio, and a loss of solids in the effluent stream. Numerous investigators have identified this problem in package plants and suggested improved maintenance and improved equipment design as solutions (7,19,20,21). Clogging of the sludge return line and solids accumulation in the clarifier are interdependent and each aggravates the other problem.

TABLE 3-10 SUBOPTIMUM BIOMASS CONCENTRATION

Plant	Average MLSS Concentration (mg/L)	Probable Reasons for Low MLSS Concentrations		
		Clogging of Sludge Return System	Hydraulic Overload	Other
1	476	Chronic	Yes	--
5	125	Frequent	Yes	Mixed liquor was pumped out in the middle of the study.
6	156	Frequent	Yes	--
7	207	-	-	165-h detention in aeration and 110-h detention in settling tanks.
8	1879	-	-	No apparent reason.
9	577	Frequent	-	-
11	280	-	-	Inadequate data to evaluate.
13	992	Frequent	-	Very low influent BOD_5.
14	1250	-	-	Very low influent BOD_5.
Total Nine				

Note: With the exception of plant 1, which had a gravity sludge return system, all plants were equipped with air-lift sludge return mechanisms.

Without proper maintenance, the accumulation of solids leads to the situation shown in Figure 3-4a. With adequate maintenance, however, the sludge return system should function normally (Figure 3-4b). Scraping solids gently towards the hopper bottom would eliminate the accumulation problem.

Sludge return clogging problems can be eliminated by replacing airlift sludge return systems with positive displacement pumps. If this is not feasible it may be possible to minimize the problem by reducing the size of the airlift sludge return lines and increasing the air flow. This will increase the velocity in the line, reducing the potential

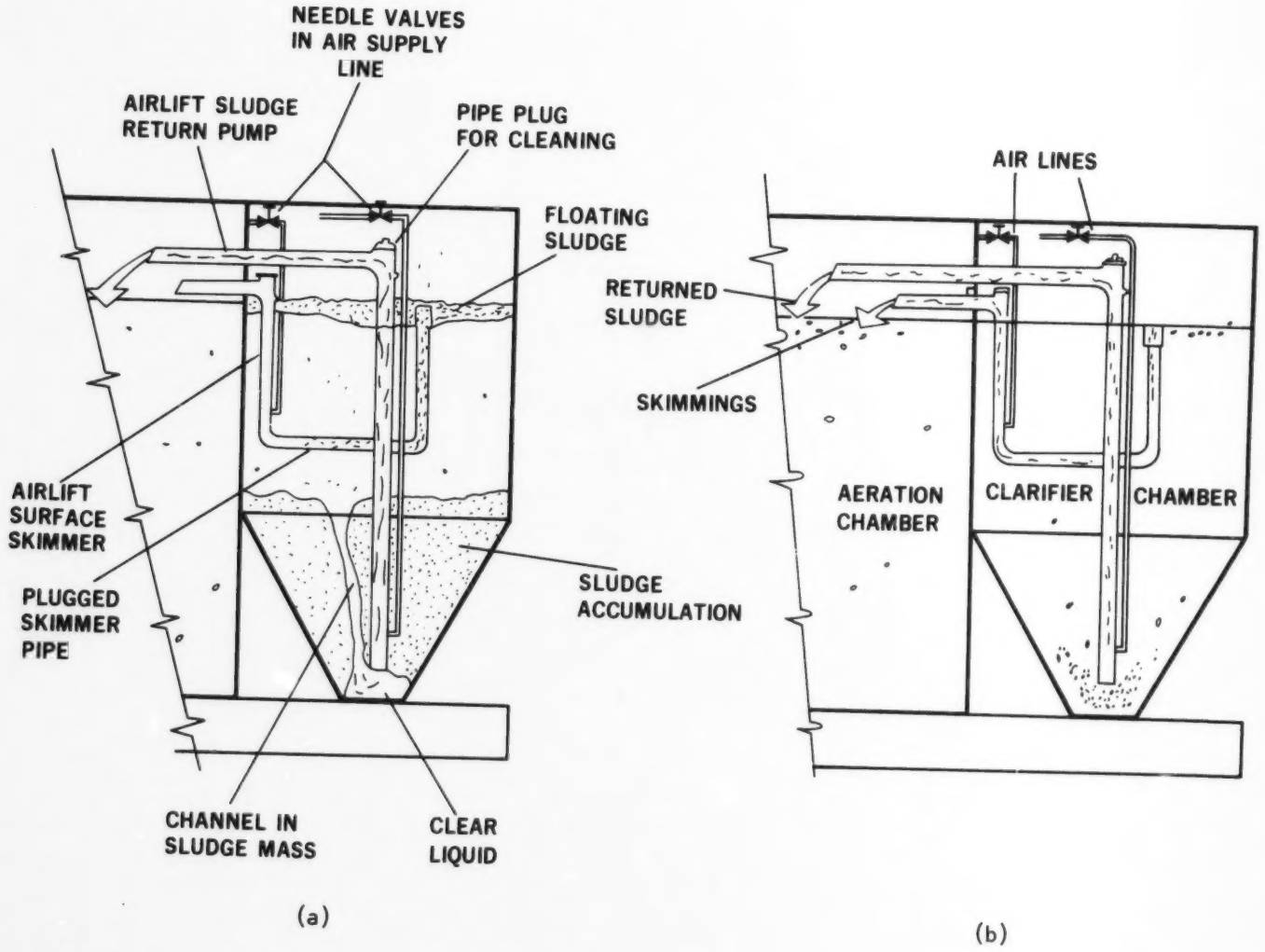


FIGURE 3-4 SLUDGE RETURN SYSTEMS
a) without proper maintenance
b) with proper maintenance

for clogging. The use of the positive displacement pump is the most desirable alternative as it eliminates the clogging and provides increased flexibility for process control.

Smith and Given suggest that in the absence of conscientious maintenance (namely, periodic manual scraping of clarifier and checking sludge and scum return pumps and pipes), it may be necessary to "design around" problems associated with clarifier operation (7). According to these authors, either an automatic sludge scraping and collection device in the clarifier or floating tube settlers in the clarifier could solve this problem. An equipment manufacturer also recommends the installation of a scraping mechanism as an integral part of clarifier design in package plants (21). These modifications are essential but they will not solve the sludge return clogging problem.

3.3.2 Flow Equalization and Additional Treatment. As mentioned in the previous section, hydraulic overloading causes the solids to pass too rapidly through the treatment system, thereby allowing insufficient time for digestion of the wastes. To remedy the problem of flow fluctuation due to hydraulic overloading (experienced in plants 1, 5, 6 and 18, Table 3-9), flow equalization and additional treatment have been suggested. Flow equalization could consist of a holding tank to absorb the hydraulic shocks during peak flows. The holding tank could also function as a primary settling tank, in which case flow equalization and additional treatment would be achieved with the same unit. The primary sludge thus generated may be pumped into the aerobic digester.

3.3.3 pH Adjustment. Addition of such chemicals as lime, soda ash and bicarbonates will increase both pH and alkalinity, and enhance the performance of those plants with low influent and mixed liquor pH (15). The cost of chemicals may be high.

3.3.4 Adjustment of Air Supply. An increase or reduction in aeration time has been suggested as a potential solution to problems in some plants (Table 3-9). An increase in the aeration efficiency can be achieved either by keeping the diffusers clean or by enlarging the blower capacity. Conversely aeration can be reduced by decreasing the aeration time of an intermittent cycle.

Highly fluctuating mixed liquor DO is a more challenging problem to solve than inadequate or over-aeration problems. Unless the loading pattern can be established, it will be difficult to set the timer so that the intermittent aeration cycle can be adjusted to meet the oxygen demand. The most realistic solution to this problem is to provide flow equalization that would equalize both the hydraulic and organic loading and, thus, the oxygen demand of the system. This eliminates the intermittent aeration cycle, the use of

which is not an acceptable operating procedure. Equalization also eliminates hydraulic surges on the clarifier with significant improvement in solid-liquid separation.

3.4 Cost Factors

Capital costs of plant equipment were available for 17 plants, as shown in the Appendix, Table Ai. However, the capital cost of installation at a site was only available for plant 10. Annual maintenance cost data for the year 1975 were collected whenever the figures were made available during the interviews. Maintenance costs were divided into personnel salaries and materials costs (chemical, power, repair, travel, etc.). While the figures for personnel salaries were available for all plants, the materials costs were incomplete because power costs were mostly not available (Appendix, Table A1).

3.4.1 Capital Cost of Plant Equipment. The costs summarized in the Appendix, Table A1 reflect the values at the time of installation which varied from December 1965 to May 1972. To enable a realistic comparison of capital costs and correlate costs with the design population equivalent (p) of the package plants, the actual costs were corrected to a common year base by employing data reported in Engineering News Record (ENR) indexes, published monthly as a materials cost index, construction cost index, etc. (22). The materials cost index was chosen as an appropriate parameter because it reflects the package plant equipment cost more accurately than the construction cost index. The information relating the corrected capital cost to the design population equivalent of the corresponding plants is presented in Table 3-11. A material cost index of 1042 (average for 20 US cities) for the month of October 1976 was chosen for the purpose of comparison, and the plant equipment costs of all plants were corrected to October 1976 values by arithmetically proportioning the costs. The design population equivalent summarized in Table 3-11 was calculated for each plant on the basis of a per person wastewater flow rate of 0.36 m^3/d.

The relationship between capital cost (C_1) and population equivalent (p) for the 17 Nova Scotian plants for which cost figures were available is:

$$C_1 = 1500\ p^{0.6} \qquad (G)$$

The correlation coefficient was 0.94, indicating an excellent correlation.

An Illinois report (23) published an equation relating costs to population equivalent of "factory built" activated sludge plants:

$$C_T = 1300\ p^{0.6} \qquad (H)$$

TABLE 3-11 CONVERSION OF CAPITAL COST TO OCTOBER 1976 INDEX

Plant	Month and Year of Installation	Capital Cost of Package Plant (excl. installation cost) (In Dollars)	Engineering News Record Materials Cost Index*	Corrected Capital Cost - Based on October 1976 Materials Cost Index of 1042	Design Capacity (m^3/d)	Design Population Equivalent at 0.36 m^3/d per person
1	December 1965	20 000	465	44 860	94	261
2	October 1967	31 600	485	67 960	117	325
4	February 1972	12 200	672	18 920	30	83
6	June 1969	17 570	567	32 320	57	158
7	May 1975	28 800	904	33 220	49	136
8	November 1975	10 522	922	11 900	14	39
9	April 1970	17 250	541	33 250	76	211
10	September 1972	72 000	681	110 170	454	1 261
11	September 1972	5 100	681	7 800	15	42
13	January 1976	25 600	945	28 240	57	158
14	December 1970	17 027	546	32 500	47	131
15	May 1972	12 343	677	19 000	19	53
16	May 1972	7 190	677	11 070	8	22
17	November 1969	33 430	542	64 270	341	947
18	September 1968	21 825	527	43 150	57	158
19	June 1970	12 200	540	23 540	38	106
20	June 1970	11 600	540	22 380	24	67

For plants 3, 5 and 12, cost figures were not available.

* ENR Index is based on a value of 100 for the year 1913. These indexes correspond to the month and year of installation of each plant and were obtained from the Engineering News Record (as average for 20 US cities) (22).

where: C_T = total construction cost (equipment plus installation) corresponding to an ENR index of 800 (20 US cities average).

p = design population equivalent.

This equation, converted to the October 1976 ENR materials cost index of 1042, becomes:

$$C_{T_1} = 1700\, p^{0.6} \qquad (I)$$

where: $C_{T_1} = C_T \times \left(\frac{1042}{800}\right)$

This equation is in excellent agreement with that derived from the present study. The difference in the two equations may be due to the fact that equation I includes the installation costs.

3.4.2 Annual Personnel Salaries. No relationship was found between personnel costs, C_2 (presented in Appendix, Table A1), and population equivalent (p); a negative correlation coefficient of 0.03 was obtained between log C_2 and log p. This implies that the number of man-hours provided for the operation of a package plant bears no relationship to its hydraulic design capacity or its size. Operators at the plant having the lowest hydraulic design capacity had a greater number of hours allocated for operation than all but one of the 20 plants; the exception was plant number 17 having a flow which was only exceeded by one plant.

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APPENDIX
SUMMARY OF SUPPORTING DATA

APPENDIX SUMMARY OF SUPPORTING DATA

Supporting data are summarized in Tables A1, A2, A3. In Table A1, the capital costs do not include the costs of installation as they were only available for plant 10 (the cost of installation at plant 10 was $24 000). In all plants, post-treatment of secondary effluent consisted of disinfection by sodium hypochlorite (HTH or Javex). In Table A3, dimensions and capacities of aeration, settling and chlorine contact tanks are shown. All aeration tanks are rectangular; the sizes are given in the order of length by width by depth. Plant 10 had a square clarifier and plant 12 had a circular clarifier. All other plants had rectangular clarifiers. All plants had one aeration, one sedimentation and one chlorine contact tank.

TABLE A1 SUMMARY OF SUPPORTING DATA

Plant	Application	Year of Construction	Cost (Dollars)			Type of Pretreatment	Sludge Return	Sludge Treatment and Disposal
			Capital[a]	Maintenance				
			Plant	Personnel	Material			
1	Subdivision	1965	20 000	1 080	3 100	BPBS, Comm. and FC	Gravity	Aerobic Digestion
2	Subdivision	1967	31 600	213	1 410	BPBS, Comm. and FC	Gravity	Aerobic Digestion
3	School	1968	N/A	500	615[b]	BPBS, Comm. and FC	Positive by Air-lift Pump	None
4	School	1972	12 200	185	331[b]	BPBS, Comm. and FC	Positive by Air-lift Pump	None
5	Subdivision	1962	N/A	900	1 700	BPBS, Comm., used to have FC but was removed	Positive by Air-lift Pump	None
6	Subdivision	1969	17 570	900	1 700	BPBS, Comm., used to have FC but was removed	Positive by Air-lift Pump	None
7	Subdivision	1975	28 800	300	110[c]	BPBS, Comm. and FC	Positive by Air-lift Pump	None
8	Training School	1975	10 522	4 250	278[b]	Comm. and FC	Positive by Air-lift Pump	Aerobic Digestion
9	Trailer Park	1970	17 250	1 500	2 080	BPBS, Comm. and FC	Positive by Air-lift Pump	None
10	Trailer Park	1972	72 000	1 040	3 800	BS, Grit Chamber and Comm.	Positive by Air-lift Pump	Withdrawl and Disposal[b]
11	Trailer Park	1972	5 100	3 600	N/A	BS and FC	Positive by Air-lift Pump	None

TABLE A1 SUMMARY OF SUPPORTING DATA (Cont'd)

Plant	Application	Year of Construction	Cost (Dollars) Capital[a] Plant	Maintenance Personnel	Maintenance Material	Type of Pretreatment	Sludge Return	Sludge Treatment and Disposal
12	Trailer Park	1965	N/A	2 029	1 800	BPBS, Comm. and FC	Positive by Air-lift Pump	None
13	Research Institute	1976	25 600	300	325[b]	BPBS, and Comm.	Positive by Air-lift Pump	Aerobic Digestion Available
14	Research Institute	1970	17 027	300	325[b]	BPBS, and Comm.	Gravity	Aerobic Digestion
15	Housing Quarters	1972	12 343	1 250	208[b]	BPBS, and Comm.	Positive by Air-lift Pump	Aerobic Digestion
16	Office Building	1972	7 190	1 250	104[b]	None	Positive by Air-lift Pump	None
17	Subdivision	1969	33 430	2 600	1 624	BPBS, Comm. and FC	Positive by Air-lift Pump	None
18	School	1968	21 825	310	555[b]	Comm. and FC	Positive by Air-lift Pump	None
19	School	1970	12 200	550	880[b]	BPBS, Comm. and FC	Positive by Air-lift Pump	None
20	Restaurant	1970	11 600	300	1 086	BPBS, Comm. and FC-but not in operation	Positive by Air-lift Pump	None

N/A - Not Available
Comm. - Comminutor
BPBS - By-pass Bar Screen
FC - Froth Control

[a] Refers to the year of construction.
[b] Power cost not included.
[c] Cost estimate is incomplete. Power cost is not available; repair cost not included because plant is under warranty.
[d] Excess sludge is withdrawn from the aeration tank for disposal approximately two or three times per year.

TABLE A2 SUMMARY OF SUPPORTING DATA

Plant	Immediate Receiving Water	Staffing Requirements: Number of Part Time Operators	Staffing Requirements: Operator Training	Man-hours Spent per Year	Routine Maintenance and Inspection Performed
1	stream entering a lake	2	Nil	365	Inspected sludge return, comminutor and froth control systems. Scum removed and cleaned.
2	stream entering a harbour	2	Nil	365	Same as above.
3	swamp behind the school	1	Level 1*	80	Lubricated and checked oil levels of equipment. Removed accumulated solids from inlet sewer and comminutor. Cleaned airlift pump, skimmer and pipings.
4	swamp behind the school	1	Level 1	30	
5	swamp	1	Nil	210	Inspected comminutor, chlorinator and pumps.
6	swamp	1	Nil	210	Same as above.
7	stream which is part of Shubenacadie Canal	1	Level 1	49	Lubricated and checked oil levels of equipment. Removed accumulated solids from inlet sewer and comminutor. Cleaned air-lift pump, skimmer and piping.
8	creek entering Atlantic Ocean	0	Level 1	790	Greased and oiled comminutor and compressors. Checked chlorinator and fan belt of compressor.
9	lake	1	Nil	400	Cleaned and oiled equipment.

* 'Level 1' training is an introductory course and is the first course in a three-part series of training courses jointly sponsored by the Federal and Provincial Departments of the Environment.

TABLE A2 SUMMARY OF SUPPORTING DATA (Cont'd)

Plant	Immediate Receiving Water	Staffing Requirements		Man-hours Spent per Year	Routine Maintenance and Inspection Performed
		Number of Part Time Operators	Operator Training		
10	brook	1	Nil	260	Oiled and greased compressors. Inspected sludge return line and skimmer cleaning.
11	lake	2	Nil	360	Diffuser cleaned, compressor oil changed, lubricated and checked electrical power (fuses).
12	underground tile system	1	Nil	260	Inspected sludge return line, skimmer and other equipment.
13	estuary	2	Level 1	525	Inspected equipment such as compressor, comminutor, air diffusers, Cl_2-tank, sludge return line and skimmer.
14	estuary	2	Level 1	525	Inspected equipment such as compressor, comminutor, air diffusers, Cl_2-tank, sludge return line and skimmer.
15	river	1	Level 1	670	Oiled and greased (monthly), skimmed floating material, inspected comminutor, compressor, skimmer, sludge return line and chlorinator.
16	river	1	Level 1	670	Oiled and greased (monthly), skimmed floating material, inspected comminutor, compressor, skimmer, sludge return line and chlorinator.

TABLE A2 SUMMARY OF SUPPORTING DATA (Cont'd)

Plant	Immediate Receiving Water	Staffing Requirements		Man-hours Spent per Year	Routine Maintenance and Inspection Performed
		Number of Part Time Operators	Operator Training		
17	river	2	Introductory course in water & sewage works	1140	Greased comminutor daily. Inspected comminutor, air diffusers, compressors, sludge return line, skimmer and chlorinator cleaned.
18	swamp	1	Level 1	51	Lubricated and checked oil levels of equipment. Cleaned accumulated solids from the inlet sewer and comminutor, inspected equipment, cleaned air-lift pump and piping system.
19	stream	1	Level 1	89	Lubricated and checked oil levels of equipment. Cleaned accumulated solids from the inlet sewer and comminutor, inspected equipment, cleaned air-lift pump and piping system.
20	stream	1	Nil	194	Oiled and greased (2-3 times/ week). Checked the colour and solids in the influent and effluent. Inspected comminutor, compressor, skimmer and chlorinator and skimmed grease from the clarifier.

TABLE A3 SUMMARY OF SUPPORTING DATA

Plant	Aeration Tank Dimensions or Capacity	Clarifier Dimensions or Capacity	Chlorine Contact Tank Dimensions or Capacity	Shape
1	5.2 m x 6.1 m x 3 m	3 m x 6 m x 3 m	2647 L	C
2	5.2 m x 7.3 m x 3 m	3 m x 7.3 m x 3 m	2647 L	C
3	4.1 m x 3 m x 3 m	0.9 m x 3 m x 3 m	0.6 m x 3 m x 1.6 m	R
4	4.1 m x 2.7 m x 2.7 m	1.5 m x 2.7 m x 2.7 m	0.6 m x 2.7 m x 1.1 m	R
5	7.6 m x 2.8 m x 3 m	2.1 m x 2.8 m x 3 m	Not measured	C
6	7.6 m x 2.8 m x 3 m	2.1 m x 2.8 m x 3 m	Not measured	C
7	5.9 m x 3 m x 3 m	2 m x 3 m x 3 m	0.6 m x 3 m x 1.6 m	R
8	4 m x 1.8 m x 2.4 m	1.4 m x 1.8 m x 2.4 m	0.6 m x 1.8 m x 0.8 m	R
9	7.5 m x 3.7 m x 2.8 m	1.8 m x 3.7 m x 2.8 m	0.6 m x 3.7 m x 0.7 m	R
10	17.1 m x 6.7 m x 3.5 m	6.7 m x 6.7 m x 3.5 m	3.7 m dia x 3 m depth	C
11	3.2 m dia x 2.1 m depth	1.6 m dia x 1.2 depth	1.6 m dia x 0.5 m depth	C
12	10.3 m x 3 m x 2.7 m	3 m dia x 2.7 depth	Not measured	R
13	6.8 m x 3 m x 3 m	2.3 m x 3 m x 3 m	Not measured	C
14	7.3 m x 3 m x 3 m	2.3 m x 3 m x 3 m	1.1 m dia x 1.8 m depth	C
15	4.3 m x 2.4 m x 2.3 m	1.8 m x 2.4 m x 2.3 m	681 L	C
16	1.7 m x 2.4 m x 2.3 m	1.8 m x 2.4 m x 2.3 m	681 L	C
17	11.7 m x 11.7 m x 3 m	3 m x 10.8 m x 3 m	Not measured	R
18	7.6 m x 2.8 m x 3 m	2.1 m x 2.8 m x 3 m	0.6 m x 2.8 m x 1.5 m	R
19	5.4 m x 2.7 m x 3 m	1.4 m x 2.7 m x 3 m	0.6 m x 2.7 m x 1.1 m	R
20	3.7 m x 2.4 m x 3.1 m	1.4 m x 2.4 m x 3.1 m	0.6 m x 2.4 m x 1 m	R

C - Circular

R - Rectangular